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Radiological imaging in cystic fibrosis: cumulative effective dose & changing trends over 2 decades

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Abstract

Objective:

With the increasing life expectancy for patients with cystic fibrosis (CF), and a known predisposition to certain cancers, cumulative radiation exposure from radiological imaging is of increasing significance. This study explores the estimated cumulative effective radiation dose over a 17 year period from radiological procedures, and changing trends of imaging modalities over this period.

Methods: Estimated cumulative effective dose (CED) from all thoracic and extra-thoracic imaging modalities and interventional radiology procedures for both adult and pediatric CF patients, exclusively attending a nationally designated CF center between 1992-2009 for >1year, was determined. The study period was divided into 3 equal tertiles and estimated CED attributable to all radiological procedures was estimated for each tertile.

Results: 230 patients met inclusion criteria (2,240 person-years of follow-up; 5596 radiological procedures). CED was >75mSv for 1 patient (0.43%), 36 patients (15.6%) had a CED between 20-75mSv, 56 patients (24.3%) had a CED between 5-20mSv and in 138 patients (60%) the CED was estimated to be between 0-5mSv over the study period. The mean annual CED/patient increased consecutively from 0.39mSv/yr to 0.47mSv/yr to 1.67mSv/yr, over the tertiles 1-3 of the study period respectively ($p<0.001$). Thoracic imaging accounted for 46.9% of the total CED and abdomino-pelvic imaging accounted for 42.9% of the CED respectively. There was an associated 5.9 fold increase in the use of all CT scanning per patient ($p<0.001$).

Conclusion: This study highlights the increasing exposure to ionizing radiation to CF patients as a result of diagnostic imaging, primarily attributable to CT scanning. Increased awareness of CED and strategies to reduce this exposure are needed.

MeSH Terms (3-5): Cystic Fibrosis [C08.381.187], Radiation Dosage [N06.850.810.250], Diagnostic Imaging [E01.370.350]

Introduction:

Experimental and epidemiological evidence has linked the cumulative exposure to ionizing radiation, even at low doses, with an age-dependent increased risk for the development of malignancy [1-4]. A number of recent studies have highlighted the issue of cumulative radiation exposure towards hospitalized patients[2,3]. However, few studies have addressed this issue in patients with chronic diseases and there are no studies to date quantifying the annual cumulative exposure to ionizing radiation incurred as a result of diagnostic and interventional radiology procedures for patients with cystic fibrosis (CF). With the progressive improvements in life expectancy for patients with CF, the cumulative exposure to ionizing radiation attributable to diagnostic imaging and interventional radiology procedures is of increasing significance[5-7].

A number of recent studies have highlighted that CF patients have an increased standardized incidence ratio (SIR; the ratio of the observed to the expected number of cancers in the cohort) of developing a large number of malignancies, with notable increases in the SIR for thoracic cancers , cancers of the digestive tract (SIR 5.6), kidney (SIR 14.0), thyroid (SIR 9.8) and lymphoma (SIR 7.3)[8]. The issue of exposure to ionizing radiation in the diagnostic range in this cohort raises additional concerns. Linking the exposure of iatrogenic ionizing radiation to malignancy is controversial, however data within the general population has approximately linked each 10 millisieverts (mSv) of radiation exposure to an incremental mean increase risk in cancer of 1 radiation induced malignancy per 1000 patients, although this risk is significantly affected by both age of exposure and gender[9-10]**.** Secondly, previous studies have proposed that additional caution is required in patient sub-groups (e.g. Crohn's disease patients) who because of their chronic relapsing illnesses require repeated diagnostic imaging throughout their lifetime and who already have an increased lifetime risk of developing cancer, may suffer as a result of possible synergy between these two factors resulting in an ever higher incidence of developing cancer [11].

The benefits of radiological imaging are well proven and have been comprehensively characterized for CF patients[12-14]. In CF patients, thoracic CT can detect lung changes from early infancy and before they become apparent by pulmonary function testing [15-16]. An increasing number of clinical trials are using thoracic CT scores as surrogate end points in their studies [17-18]. Additionally, some centers use high resolution CT in the routine monitoring of disease progression for pediatric patients with CF[19].

This is the first study to examine the cumulative effective radiation dose (CED) incurred by a cohort of adult and pediatric patients with CF, and the changing trends in use of radiological imaging modalities in this cohort, over 17 years. It is also the first study to characterize relative anatomical radiation distribution including the percentage of cumulative exposure arising from thoracic and abdomino-pelvic imaging and the relationship between clinical phenotype and CED.

Methods:

Study Population:

All pediatric and adult patients with CF who exclusively attended a nationally designated Adult or Pediatric CF center , for all medical therapy for > 1year from the 1st July 1992 to the time of lung transplantation, hospital treatment transfer or death until the study end date of 1st May, 2009 were included in this study. Ethical approval for the study was granted by the institution's research ethics committee. Approval number (reference number) for this study: ECM 4(z)03/03/09. All demographic, clinical data and hospital attendances were obtained by chart review. Lung function was measured in accordance with the standards set out by the European Respiratory Society and recorded as maximum annual FEV_1% predicted using the European Community for Coal and Steel (ECCS) reference values[20].

Data Source:

Details of all imaging studies and interventional radiology procedures performed on adult (>18yrs) and pediatric (<18yrs) patients in the study cohort over the 17 year study period 1st July 1992 to 1st May 2009 were obtained from the computerized radiology information system of the radiology department. All studies were requested for clinical purposes only, by experienced hospital clinicians, predominantly by attending pediatricians and attending pulmonologists with a special interest in cystic fibrosis. The CED was measured in millisieverts (mSv), a measure designed to represent the overall detrimental effect of a non-uniform ionizing radiation exposure and useful for population-level comparisons across different types of radiation exposure [21]. As per previous studies [11 22], estimations were based on a recent article by Mettler at al, which provided a compilation of the mean effective doses for radiological and nuclear medicine examinations from the recent published literature, across the USA, Canada, Japan, Australia and Western Europe, over a similar time period as this study[23]. In circumstances where this source was insufficient, estimates were calculated from other published sources or extrapolated from doses reported for similar procedures relevant to our studied population over a similar time period and using similar dose calculation methodology [24]. CED was determined for general radiography (Gen), computed tomography (CT), general interventional procedures (GIV), nuclear medicine (NM), fluoroscopy (Fl) including all barium examinations (Ba), and data were then subcategorized into the anatomical area imaged as thoracic, abdomino-pelvic and other. All computed tomography (CT) scans during the study period (1992-2009) were performed using either an incremental protocol on either a single slice CT (Siemens Medical Solutions, Erlangen Germany) or a four slice detector CT (Toshiba Aquilon, Toshiba Medical Systems, Zoetermeer, The Netherlands).

Pediatric effective doses for chest radiographs, abdominal films and barium studies were calculated using the presets for pediatric patients aged 1, 5, 10 and 15 years in the software package PCXMC (version 1.5)[25] in conjunction with local hospital exposure parameters and protocols. Typified normalized effective doses for pediatric CT scanning were calculated based on validated anatomically-specific Monte Carlo phantom simulations for 1, 5, 10 and 15 year olds[23] (table 1) .

Statistical Analysis:

The study period was divided into three tertiles of equal duration from 1st July 1992- 28th February 1998 (Tertile 1), 1st March 1998-30th November 2003 (Tertile 2), and 1st December 2003-1st May 2009 (Tertile 3). Data compilation and statistical analyses were performed using Microsoft Access 2007 (Microsoft Corporation, Washington, USA) and SPSS version 15 (SPSS Inc, Chicago IL, USA). Algorithms calculating the age of each patient at time of scanning and adjusting to the closest categorical age of 1, 5, 10, 15 years old or adult as appropriate were established and the person years of follow up in each tertile determined. Comparison between groups was performed using Mann Whitney U tests or Pearson's Chi-squared for categorical variables. Spearman analysis was used for comparisons of non-parametric data where appropriate. Comparison across 3 or more groups was performed using ANOVA or Kruskal Wallis tests in accordance with their distribution. A type I error rate ≤ 0.05 was considered significant.

Results:

Study population: 230 patients met inclusion criteria and were included in the final analysis. The mean age of patients at the end of tertile 3 was 21.5 years (SD +/-11.6); mean FEV_1 % predicted was 65.8% (SD +/- 27.3%). 7 patients received lung transplantations during the study period and 42 patients died during the study period, 1 from hepatocellular carcinoma.

Imaging Modality:

There were 5596 radiological procedures: General radiographs n= 4730, Ultrasonography n= 406, CT n= 241, interventional procedures n=127, fluoroscopy n=74 and nuclear medicine n=18, over the 2,240 person years of follow up.

Cumulative Effective Dose:

Over the total study period 1 patient (0.43%) had a CED >75mSv, 6 patients (2.6%) had a CED 50-75mSV, 30 patients (13%) had a CED 20-50mSv, 26 patients (11.3%) had a CED 10-20mSv, 29 patients (12.6%) had a CED 5-10mSV and 138 patients (60%) had a CED between 0-5mSv. In total 63/230 (27.4%) of patients had a CED >10mSv over the study period. Plain radiographs account for 74% of the total number of studies, resulting in 6% of total cumulative radiation exposure for the most recent tertile (tertile 3, see figure 1). Conversely, CT accounted for 8% of total number of studies whilst resulting in 74.8% of total radiation exposure in tertile 3 (Figure 1). A breakdown analysis of the 10% of patients with the highest CED showed 61.9% related to CT, 10.4% from fluoroscopy, 12.7% from general radiography and 15.0% from interventional procedures.

Changing trends over time:

The mean number of radiological procedures for tertile 1-3 was 2.89 procedures per person per year for tertile 1, 2.7 procedures per person per year for tertile 2 and 2.71 procedures per person per year for tertile 3. The equivalent annual mean effective dose (aMED) was 0.39 mSv per person per year for tertile 1, 0.47mSv per person per year for tertile 2 and 1.67mSv per person per year for tertile 3 ($p<0.001$) (table 2). The increased aMED predominantly related to a 5.9 fold increase in the number of CT studies over this time ($p<0.001$). Similar trends were seen in the pediatrics' subgroup analysis (table2).

Correlation between clinical phenotype and CED: CED correlated with age ($r=0.307$; $p<0.001$) and in subgroup analysis of adult patients at the end of tertile 3, CED correlated inversely with FEV_1% predicted ($r=0.182$; $p<0.04$). There was no correlation between mean annual effective dose and gender ($p=0.125$) or cystic fibrosis class mutation ($p=0.122$).

Anatomical Area Imaged:

Cumulative radiation exposure, for the whole population, from thoracic imaging, as a percentage of total CED was 46.9% over the 3 tertiles with relative exposure of 36%; 34.4% and 51.7% for tertiles 1-3 respectively, correlating with the increased use of CT thorax. Of the total radiation exposure to the thorax, 76.4% (748mSv) was from CT thorax (n=130 scans of thoracic region), 9.5% (71.3mSv) from plain radiography, 0.8% (7.93mSv) from fluoroscopy, and 15.5% (152mSv) from interventional procedures (figure 2)

Cumulative radiation exposure, for the whole population, from abdominal imaging as a percentage of total CED was 42.7% over the 3 tertiles with cumulative exposure per tertile of 50%; 45.3% and 41% for tertiles 1-3 respectively reflecting both an increased use of abdomino-pelvic CT imaging with a decreasing use in fluoroscopy. Overall the CED to the abdomino-pelvic area increased significantly across the 3 tertiles, however there was a relative decrease in the percentage contribution from abdomino-pelvic imaging due to the more significant increase in thoracic imaging over the same time period. Of the total radiation exposure to the abdomino-pelvic region; 53.5% was from abdomino-pelvic CT imaging, 11.9% from plain radiography, 25.6% from fluoroscopy, and 9.0% from interventional procedures.

Discussion:

This is the first study to calculate annual CED from all diagnostic imaging and interventional radiology procedures in patients with cystic fibrosis. 27.3% of our patients had an estimated CED exposure of >10mSv over the study period. Although controversial, an exposure of 10mSv of radiation dose has been predicted to result on average in 1 radiation induced malignancy per 1000 patients[10]. Recent studies have highlighted the increased risk for certain malignancies in patients with CF[8]. Several epidemiological studies have shown direct evidence of increased cancer-related mortality following long-term exposure to low levels of ionizing radiation, including diagnostic radiation [10 26], and that this cancer risk follows a "linear no threshold" risk, indicating all radiation exposure may pose a risk of developing cancer[27]. Studies have suggested that the majority of physicians are not aware of the effective radiation dose associated with radiological procedures, nor do they discuss the risks and benefits of CT and other imaging examinations with their patients [28]. One study found 75% of radiologists and physicians significantly underestimated the radiation dose from a CT scan [28]. Our paper address's these issues and generates a summary of effective doses for common adult and pediatric imaging modalities, which clinicians can apply to their practice.

The present study demonstrates a significant increase in the annual mean effective dose to our patients over the past 17 years, with a mean annual exposure of 1.67mSv per patient in the most recent tertile. This dose may appear relatively modest, given for example a background environmental radiation exposure annually of ~3.9mSv/yr amongst the Irish population[29], however this represents a significant exposure for such a young cohort of patients, made all the more pertinent given the progressive increased life expectancy for these patients with improved management of cystic fibrosis[4]. Over the 3 tertiles the frequency of medical imaging remained relatively constant; however there was a significant shift in the use of imaging modalities. The single largest contributing factor to the increased radiation exposure was the 5.9 fold increase in all CT imaging (thoracic, abdomino-pelvic and other) from the 1st tertile to the 3rd tertile. This is consistent with international data on the rapidly increasing availability and utilization of CT imaging in clinical medicine [30].

The changing trends in radiation exposure held similar results for both adult and pediatric populations. The pediatric effective doses we established, are frequently much larger than adult doses (table 1), this is due to the thinner torso in children providing less shielding of organs from the radiation exposure[1]. In CT, based on the exposure factors used and in the absence of tube current modulation, there is a decrease in effective dose with increasing age. This relates to the increased dose administered per unit of body mass for children as highlighted recently in the “Image Wisely” campaign of the joint North American task force on adult radiation protection[31]. Plain film radiography, however allows for greater dose reduction in children, as the exposure parameters required are significantly lower than those used in CT. Increased radiosensitivity in children still exists but the radiation dose decreases with decreasing age, resulting overall in a decreasing effective dose[32]. The increasing use of CT imaging as a routine procedure in some centers and the recent studies which suggest that HRCT findings frequently pre-date changes in lung function and chest radiograph for pediatric patients, highlights the need to develop further strategies to minimize the risks of radiation exposure to these patients[33]. Children, particularly females, are inherently more sensitive to radiation exposure. This radiosensitivity relates to a large proportion of dividing cells and a longer time for a potential cancer to develop[1]. De Gonzalez et al estimated the lifetime risk of radiation induced cancer for CF patients from a modern HRCT thorax protocol at 2 years of age to be 24 per 100,000 for females versus 6 per 100,000 males, reducing to 1 per 100,000 for a 50 year old female and 0.3 per 100,000 for a 50 year old male[34]. The studies to date predicting radiation induced cancer risk from annual thoracic CT for CF patients[34] have assumed the cancer rates to be the same as the general population, however recent data supports an increased standardized incidence risk ratios for all cancers in CF patients, suggesting these patients may have an intrinsic increased risk of malignancy. For anatomical reasons, the thyroid radiation exposure is higher in pediatric patients undergoing chest radiographs and thoracic CT imaging and the routine use of thyroid and breast shields should be seriously considered in this cohort of patients [35].

Despite the fact that greater than 90% of CF patients die from respiratory failure, this study highlights that over half of all radiation exposure is related to extra thoracic imaging modalities, contrary to what one might have expected. CF is a multi-system disorder and patients with cystic fibrosis are particular prone to both primary and secondary gastrointestinal disturbances including constipation, distal intestinal obstruction syndrome, acute and chronic pancreatitis and nutritional deficiency. These conditions frequently require diagnostic imaging, which is often of a significantly higher radiation dose than thoracic imaging[36]. In our cohort of patients, 42.7% of radiological imaging was directed at the abdomino-pelvic region. There are consistent reports of an increased standardized incidence ratio for digestive tract and other abdominal malignancies in CF patients compared to the general population [8 37]. This malignancy risk is likely to be multifactorial, potentially as a result of the inflammation associated with chronic pancreatitis [38], low serum vitamin D levels and an increasing frequency of lung transplantation with associated immunosuppression[39]. The high abdomino-pelvic radiation exposure is likely to pose an additional risk factor for these malignancies.

There are a number of available strategies for reducing radiation exposure in patients with CF[40]. Patients with CF frequently have a smaller body habitus and reduced body mass indices, so specific low-dose CF protocols optimizing specific parameters such as the millamperes (mA) to patient weight need to be considered[41]. Reducing the mAs from 180 to 45 for a conventional thoracic HRCT scan can result in a 4 fold reduction in radiation exposure without any significant difference in image quality [42]. Additionally, over 97% of CT Thorax scans have significant supra-apical and infra-pulmonary unnecessary imaging, resulting in increased exposures to the thyroid and abdominal regions [43]. For incremental CT thorax imaging in CF patients, the validity of reducing the number of images per CT examination has generated conflicting results, one study has shown an equivalent score using CT cuts from 6 pre-selected sections in a cohort of children with CF [44], whilst others report a reduced sensitivity to detect changes when the image interval is >10mm in children with CF [45]. With proper attention to detail of scanning parameters radiation dose can be reduced substantially compared to routine chest CT. Strategies currently available for optimization of CT radiation dose include the use of automatic tube current modulation, iterative reconstruction techniques and noise reduction filters which can lead to significant reduction in radiation exposure without significant impact on image quality[27]. As a result of the preliminary results of this study, we recently implemented a new thoracic low dose thin slice CT protocol for pediatric patients with CF which achieved significant reductions in mean effective doses[14]. Close attention needs to be given to the information gained from each imaging request to ensure that the examination is indicated and could not be replaced by an imaging study which does not expose the patient to ionizing radiation (e.g. ultrasound or MRI). Also it is very important to limit exposure to extra-thoracic organs including the development of low dose abdomino-pelvic CT protocols.

The advantage of detecting early changes on CT imaging awaits additional confirmation, some authorities feel strongly that the structural information gained by the use of CT scanning helps to tailor treatments, reducing under and over treatment for patients, but to date there are no studies proving such a benefit [13 19]. The current guidelines suggest there is insufficient evidence to recommend use of chest CT scans for routine surveillance but suggest chest CT scanning may be helpful in infants with symptoms or signs of lung disease who fail to respond to basic interventions[46]. Future studies are also needed to delineate the role of novel strategies in thoracic imaging, including the use of hyperpolarized helium magnetic resonance imaging[47] and positron emission tomography[40].

This study has a number of limitations, notably it represents the radiation exposure in a single tertiary referral cystic fibrosis center. However, the use of a nationally designated CF center acting as both the primary and secondary care facility, regardless of health insurance status, ensured the accuracy of capturing of all imaging studies for this cohort of patients. We acknowledge that retrospective radiation dose exposures appropriate for the period of study involved were used. With technological advances it has been suggested that a reduction in radiation exposure of over 75% can be safely achieved using more modern low-dose CT thorax protocols [48], however this may be offset with the increasing use of spiral CT scanning and potentially by the recent suggestions to monitor disease progression using combined PET/CT imaging[49-50]. The modern use of helical CT scanning in CF patients[51] has increased the diagnostic sensitivity in detecting peripheral thoracic changes[33] but incurs significantly higher radiation exposures compared to standard incremental scans of up to 3 mSv per CT thorax. Inevitably there will be variation in clinical practice between centers', one previous French study identified a mean cumulative effective dose from CT scans in CF patients of 19.5 mSv [52], with a mean patient exposure to 3.4 CT scans. The annual radiation exposure in our cohort of patients with CF is relatively low, with mean annual exposures of 1.667mSv in the most recent tertile 3, this compares to an annual exposure dose of 8.1mSv in a cohort of patient with Crohn's disease at the same institute. It is important to note that only 1 patient (0.43%) had an exposure of >75mSv over the 17 yr period, compared to 15.5% of Crohn's patients[15] and 13% of hemodialysis patients having an exposure of >75mSv over the same time period at our institute[16]. However, the critical difference is the young age patients with CF are exposed to radiation and the chronic progressive nature of CF from early childhood. Our center follows the 3 fundamental principles of radiation protection: justification, dose optimization through the "as low as reasonably achievable" (ALARA) principle and dose limitation, as set out in the International Commission of Radiological Protection [53].. As a result of this, we have not yet adopted the use of routine CT scanning into clinical practice given the absence of any proven benefit in clinical outcome for such a measure[52]. This study is therefore likely to represent a conservative estimate for the annual cumulative effective dose for radiological imaging in CF patients and for the changing trends in CT imaging over the past 17 years. Urgent consideration should be given to the development of low-dose imaging protocols and to regular monitoring and recording of CED for patients, particularly in identifiable groups where exposure levels may become high, as in our cohort and in many chronic diseases. Strategies to prospectively monitor cumulative dose may include recommendations such as: the creation of dose registries; the mandatory recording of dose within the examination images or report, recording of dose within the patient's medical record and mandatory accreditation of imaging facilities. As a result of this study we are currently implementing a policy of recording the effective dose through the picture archive communication system (PACS) at our institute, to allow for ongoing monitoring and auditing of radiation exposure with each imaging examination[54].

Conclusion:

Patients with CF are exposed to high radiation doses from a young age, exacerbated by the increasing use in CT imaging. Strategies need to be developed and implemented with regard to radiation exposure reduction for both thoracic and extra-thoracic imaging in this cohort of patients.

Disclosures:

There are no competing interests for this paper. The authors grant exclusive publishing rights to the journal, and full ethics board approval was obtained as outlined in the body of the paper.

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Legend for Table 1: The effective doses of frequent medical imaging procedures used for CF patients.

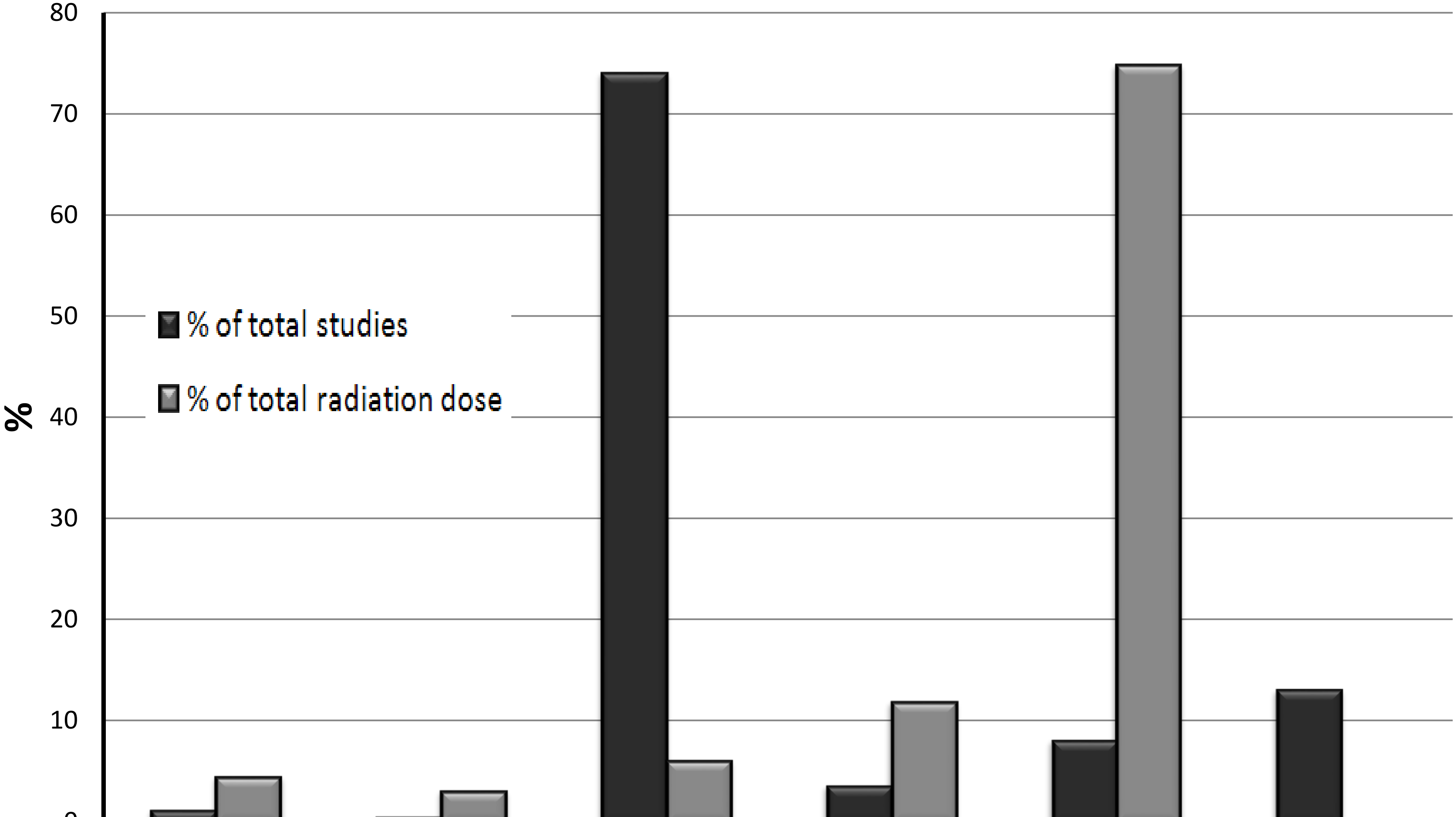
Legend for Table 2: Total radiation dose per patient year (PPY) across the 3 tertiles for all study subjects and secondly for pediatric patients only.

Legend for Figure 1: Relative contribution of each radiological imaging modality to cumulative radiation exposure for tertile 3.

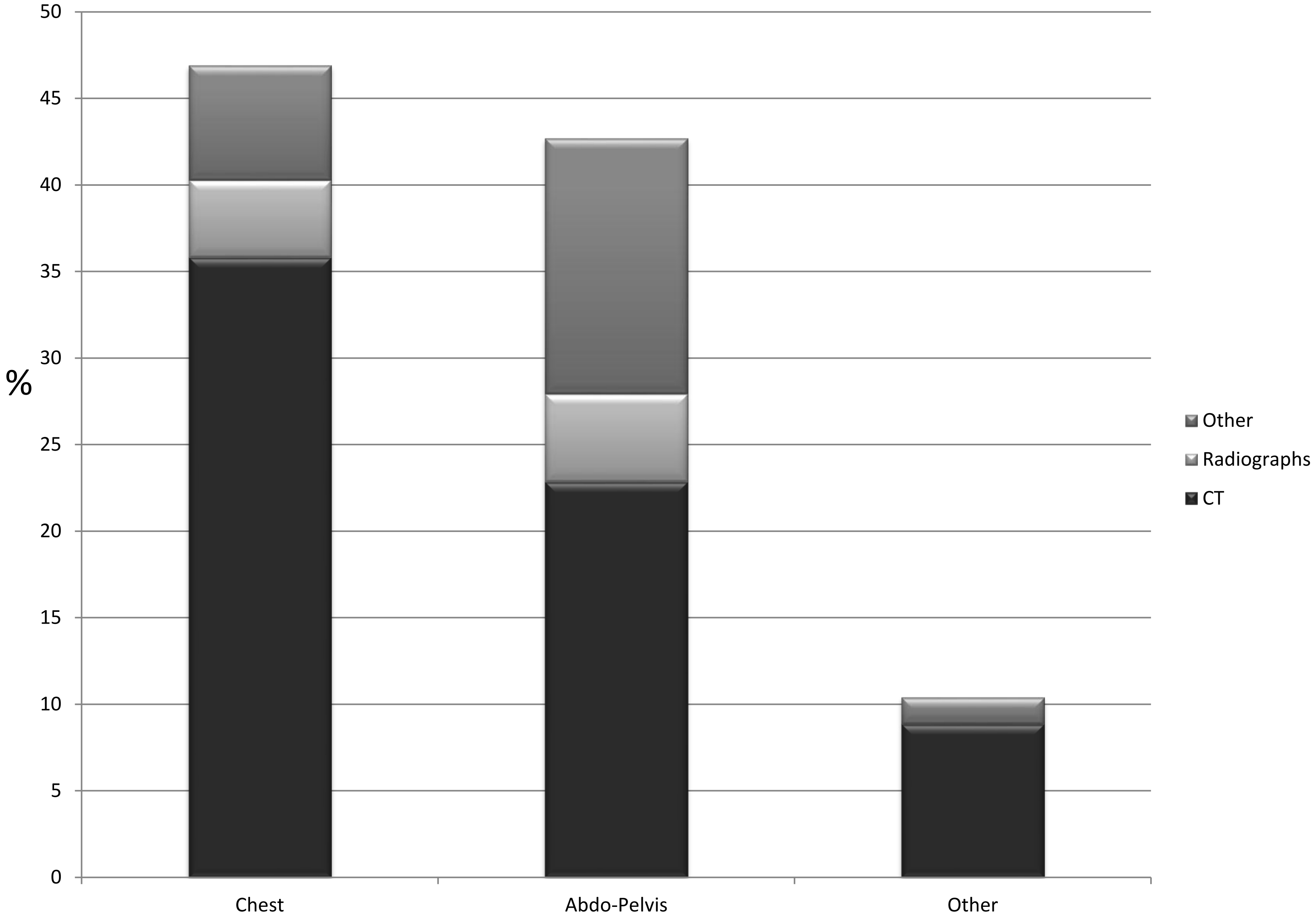
Legend for Figure 2: Regional percentage breakdown of total radiation dose exposure to thorax, abdomino-pelvic and other body parts over tertiles 1-3 for the studied population (adult and pediatric inclusive).

Procedure	1yr (mSv)	5yr (mSv)	10yr (mSv)	15yr (mSv)	≥18yr (mSv)
CXR PA	0.003	0.005	0.01	0.014	0.02
Radiograph of abdomen	0.02	0.04	0.1	0.14	0.23
Conventional CT Thorax	13.3	11.2	9.8	7.7	7.0
HRCT Thorax	2.85	2.4	2.1	1.65	1.5
CT abdomen	16	12.8	12	8.8	8
CT Pulmonary Angiogram	28.5	24	21	18	15
Barium Meal	1.28	0.82	0.93	1.63	2.32
Barium Swallow	1.16	0.78	1.09	0.75	0.77
Radiograph Lumbar Spine					1.5

Population	All subjects				Pediatrics only			
Tertile	1st	2nd	3rd	**p-value**	1st	2nd	3rd	**p-value**
Number of subjects	132	157	199		105	115	115	
Cumulative Follow Up (years)	599.8	702.6	938.0		435.83	452.17	470.67	
All investigations								
Number PPY	2.89	2.70	2.71	0.86	2.82	2.49	2.04	0.11
Total dose PPY, (mSv)	0.39	0.47	1.667	**<0.001**	0.403	0.303	0.788	**0.01**
Chest Radiographs only								
No. PPY	2.07	1.93	1.66	0.31	1.98	1.76	1.35	**0.03**
Total dose PPY, (mSv)	0.03	0.03	0.03	0.92	0.02	0.02	0.02	0.22
Abdominal Radiographs Only								
No. PPY	0.23	0.24	0.19	0.81	0.23	0.27	0.07	0.11
Total dose PPY, (mSv)	0.03	0.03	0.04	0.76	0.03	0.03	0.008	0.07
Total CT								
No. PPY	0.035	0.046	0.210	**<0.001**	0.042	0.033	0.108	**0.006**
Total dose PPY (mSv)	0.136	0.179	1.27	**<0.001**	0.192	0.084	0.581	**0.002**
Thoracic CTs only								
No. PPY	0.015	0.018	0.125	**<0.001**	0.024	0.018	0.063	**0.01**
Total dose PPY, (mSv)	0.087	0.061	0.778	**<0.001**	0.146	0.045	0.327	**0.02**
Abdomino-Pelvic CT Only								
No. of PPY	0.001	0.010	0.058	**<0.001**	0.002	0.002	0.028	**0.001**
Total dose PPY, (mSv)	0.008	0.082	0.444	**<0.001**	0.010	0.012	0.218	**0.001**
Other CTs								
No. PPY	0.019	0.018	0.027	0.65	0.017	0.014	0.018	0.94
Total dose PPY (mSv)	0.041	0.036	0.054	0.68	0.036	0.027	0.036	0.92
Total interventional studies								
No. of PPY	0.034	0.039	0.101	**0.01**	0.018	0.016	0.033	0.55
Total dose PPY (mSv)	0.038	0.069	0.172	0.06	0.019	0.008	0.086	0.06
Total Barium Studies								
No. PPY	0.048	0.039	0.014	**0.01**	0.048	0.048	0.012	**0.03**
Total dose PPY (mSv)	0.104	0.093	0.055	0.36	0.096	0.107	0.026	0.05
Total Nuclear Medicine Studies								
No. PPY	0.001	0.009	0.011	0.29	0.002	0.008	0.006	0.37
Total dose PPY (mSv)	0.009	0.051	0.063	0.37	0.011	0.038	0.034	0.49



	Fluroscopy	Nuclear Medicine	Radiographs	General Intervention	Computed Tomography	Ultrasound
% of total studies	1.1	0.4	74	3.5	8	13
% of total radiation dose	4.4	3	6	11.8	74.8	0


50
45
40
35
30
25
20
15
10
5
0
%
Chest
Abdo-Pelvis
Other
Other
Radiographs
CT

Radiological imaging in cystic fibrosis: cumulative effective dose & changing trends over 2 decades

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